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for

METHOD AND APPARATUS FOR ULTRASOUND IMAGING WITH AUTOFREQUENCY SELECTION

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BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention is directed at medical imaging technology, and more particularly to a method and apparatus for ultrasound imaging with autofrequency selection.

DESCRIPTION OF THE RELATED ART

[0002] Medical imaging technology is used to improve the diagnosis and treatment of medical conditions. Presently available medical imaging technology includes a wide variety of ultrasound, X-ray, nuclear, magnetic resonance imaging (MRI) and other imaging systems.

[0003] In these medical imaging technologies, various parameters may be controlled that affect the resultant image. By way of example, with catheter-based ultrasound imaging technology, the imaging beam aperture size, imaging beam frequency, and apodization parameters may be adjusted as described in U.S. Patent No. 6,629,929 to Jago ("Jago" hereafter) and U.S. Patent No. 6.354,997 to Holley ("Holley" hereafter), which are incorporated by reference herein in their entirety. Other adjustable parameters for ultrasound and non-ultrasound imaging technologies also exist.

[0004] To adjust a parameter in a typical catheter-based ultrasound imaging system, a user inputs a desired parameter change, which is

then implemented by the particular imaging system. This requires the user to know how the parameter change will affect the image, and may require the user to iteratively try a number of different parameter changes to achieve a desired result. Thus, this process may be tedious, time consuming, and involve significant user-system interaction.

[0005] Other problems with the prior art not described above can also be overcome using the teachings of the present invention, as would be readily apparent to one of ordinary skill in the art after reading this disclosure.

SUMMARY OF THE INVENTION

[0006] An ultrasound imaging system includes an interface for receiving user input and a controller coupled to the interface, the controller being adapted and configured to adjust parameters for a catheter-based ultrasound probe in response to received user input. User input may be in the form of a desired imaging depth or user designation of a feature within an image, such as by means of a touch screen. The controller is programmed to receive a user request for a desired imaging depth, automatically determine an imaging frequency that corresponds to the desired imaging depth, and adjust the imaging frequency of the catheter-based ultrasound probe to the determined imaging frequency that corresponds to the desired imaging depth. The controller may be further programmed so the imaging frequency is selected from a range of incremented frequencies separated by increments of about 0.1 MHz to about 0.5 MHz within a range of about 2

MHz to about 20 MHz. The controller may be further programmed so the imaging frequency is set to scan through a range of frequencies. The controller may be further programmed to receive an ultrasound image from the catheter-based ultrasound probe, determine a signal attenuation in the received ultrasound image at the determined imaging frequency, determine an imaging frequency that corresponds to the determined signal attenuation, and adjust the imaging frequency of the catheter-based ultrasound probe to the determined imaging frequency that corresponds to the determined signal attenuation. The controller may be further programmed to compare the determined signal attenuation to a predicted signal attenuation, and adjust the imaging frequency to the determined imaging frequency that corresponds to the determined signal attenuation if the determined signal attenuation diverges from the predicted signal attenuation by at least a known value. The controller may be further programmed to process a first image of a feature of interest imaged at the determined imaging frequency, adjust the imaging frequency of the catheter-based ultrasound probe by a delta-frequency, process a second image of the feature of interest imaged at the delta-frequency adjusted imaging frequency, compare a resolution of the first image to a resolution of the second image, and adjust the imaging frequency to the determined imaging frequency if the resolution of the first image is better than the resolution of the second image.

[0007] A method of controlling an ultrasound imaging system includes receiving a user request for a desired imaging depth or change in the present imaging depth, automatically determining an imaging frequency that corresponds to the desired imaging depth, and adjusting the imaging frequency of a catheter-based ultrasound probe to the

determined imaging frequency that corresponds to the desired imaging depth. The desired imaging depth may be received as a user request for a scan through a range of frequencies to identify features at various depths. The desired imaging depth may be received as a user designation of a feature within an image, and determining the imaging frequency involves determining an imaging frequency that corresponds to the user designated feature. The imaging frequency may be selected from a range of incremented frequencies separated by increments of about 0.1 MHz to about 0.5 MHz within a range of about 2 MHz to about 20 MHz. The imaging frequency selection may be conducted as a scan through the range of frequencies. The method may include receiving an ultrasound image from the catheter-based ultrasound probe, determining a signal attenuation in the received ultrasound image at the determined imaging frequency, determining an imaging frequency that corresponds to the determined signal attenuation, and adjusting the imaging frequency of the catheter-based ultrasound probe to the determined imaging frequency that corresponds to the determined signal attenuation. The method may further include comparing the determined signal attenuation to a predicted signal attenuation, and adjusting the imaging frequency to the determined imaging frequency that corresponds to the determined signal attenuation if the determined signal attenuation diverges from the predicted signal attenuation by at least a known value. The method may further include processing a first image of a feature of interest imaged at the determined imaging frequency, adjusting the imaging frequency of the catheter-based ultrasound probe by a delta-frequency, processing a second image of the feature of interest imaged at the delta-frequency adjusted imaging frequency, comparing a resolution of the first image to a resolution of the second image, and adjusting the imaging frequency to the

determined imaging frequency if the resolution of the first image is better than the resolution of the second image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a flowchart of a method of controlling an ultrasound imaging system according to an embodiment of the present invention.

[0009] Figure 2 is a flowchart of a method of compensating for signal attenuation in an ultrasound imaging system according to an embodiment of the present invention.

[0010] Figure 3 is a flowchart of a method of auto-scanning a plurality of imaging frequencies in an ultrasound imaging system according to an embodiment of the present invention.

[0011] Figure 4 is a flowchart of a method of optimizing an image in an ultrasound imaging system according to an embodiment of the present invention.

[0012] Figure 5 is a block diagram of an exemplary ultrasound imaging system usable with various embodiments of the present invention.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0013] Reference will now be made in detail to exemplary embodiments of the present invention. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[0014] An exemplary ultrasound imaging system usable with various embodiments of the present invention is shown in the block diagram of Figure 5. The exemplary ultrasound imaging system includes a workstation 30, having an interface 35 (e.g., a keyboard, mouse, touchscreen display, etc.), a controller, and a display. The workstation 30 is coupled to an ultrasound probe 10 via a percutaneous catheter 20. The controller may be a computer, such as a personal computer, an internal microprocessor, or an application specific integrated circuit (ASIC) operating software that causes the controller to perform the control functions described herein. In this regard, the controller is preferably programmable so as to perform various processes and method steps described in greater detail below. Other configurations are also contemplated, and the system may or may not include further components as would be readily apparent to one of ordinary skill in the art after reading this disclosure.

[0015] A method of controlling an ultrasound imaging system according to a first embodiment of the present invention is shown in the flowchart of Figure 1. Specifically, in step 110, the ultrasound imaging system receives a user request for a desired imaging depth. By way of example, a user may: (1) enter a desired imaging depth (e.g., 5 cm) into a keyboard type interface, such as or including keys, buttons, toggle switches, rotary knobs, or various keypads, for example; (2) select an increase or decrease (i.e., a change) in a present imaging depth on a touchscreen display type interface; (3) issue a voice command to increase or decrease the present imaging depth interpreted by a voice recognition type interface; (4) select one of a list of possible imaging depths listed on a display using a mouse type interface; or (5) select any imaged feature or position on a video display showing the real-time

image received from the ultrasound imaging system, such as by touching a touch-screen display or using a pixel-detecting pen coupled to the system to indicate the depth (and/or feature) for which optimized imaging is desired. In the embodiment that includes option (5), the imaging distance can be automatically calculated based upon the distance from the imager to the indicated point on the display. Other techniques for receiving a user request are also contemplated.

[0016] After the user request has been received in step 110, the ultrasound imaging system then automatically determines an imaging frequency that is calculated or known to correspond to the desired imaging depth in step 120. Step 120 may include processes such as retrieving a corresponding frequency from an electronic lookup table or database based upon the desired depth, or calculating a corresponding frequency using any one of a number of algorithms as would be readily apparent to one of ordinary skill in the art after reading this disclosure. The attenuations of sound in various tissues, including in blood, as a function of frequency have been measured and therefore are known and can be reduced to a look up table. Alternatively, the measured attenuation of sound in blood may be transformed into a computational algorithm, such as by a curve fit, that the imaging system can perform using the indicated imaging depth as an input. For example, the imaging depth of an ultrasound imager due to attenuation of sound in blood is an approximately linear gradient (classically expressed in dB/cm/MHz), such that the imaging depth at 4.5 MHz is about 11 cm and the imaging depth at 7.0 MHz is about 6 cm. Step 120 may be based on assumed physical properties or may include measuring physical properties of the fluids and/or tissues between the ultrasound sensor and the desired depth using data obtained from the ultrasound

sensor or other sensors. In an embodiment, the look up table or algorithm may include attenuation effects of tissues, such as heart muscle or connective tissue in addition to blood.

[0017] In step 130, the medical imaging system then adjusts the imaging frequency of the system to the imaging frequency determined in step 120. In this manner, the medical imaging system automatically adjusts the imaging frequency in accordance with manual adjustment of the desired imaging depth. By automatically adjusting the imaging frequency, the medical imaging system can optimize the imaging frequency to match the desired imaging depth without requiring any further user interaction than the request for the desired imaging depth. As such, user interaction is minimized and the most optimized image is generated.

[0018] In an embodiment, the imaging system may also automatically adjust the time-gain compensation (up or down) in conjunction with adjusting the imaging frequency. The time-gain compensation also compensates for the attenuation of sound by blood or tissues. Since the time at which an echo signal is received is directly related to the distance the associated sound traveled (i.e., to and from the echoing structure), sound attenuation can be compensated for by amplifying the echo signals by an increasing amount based upon the time after the transmission pulse that the echo signal is received. The time-gain compensation may be adjusted according to an algorithm (such as a linear adjustment). However, applying too high a level of amplification in order to capture distant echo signals may result in greater noise in the image. Also, the appropriate time-gain may vary with imaging frequency. In this embodiment, when the imaging system receives a request for a new imaging depth, the system automatically adjusts the

time-gain compensation to provide appropriate signal gain at the approximate time echo signals from that distance will be received at the ultrasound transducers.

[0019] According to an embodiment of the present invention, the catheter-based ultrasound probe includes an array of ultrasound transducers for generating ultrasound pulse(s), the array of ultrasound transducers, such that the system has an imaging frequency range of about 2 MHz to about 20 MHz. Preferably, the system is adjustable from about 2 MHz to about 20 MHz in about 0.5 MHz intervals. In this manner, the medical imaging system may adjust the imaging frequency to an imaging frequency selected from the group consisting essentially of 2.0 MHz, 2.5 MHz, 3.0 MHz . . . 19.0 MHz, 19.5 MHz, 20.0 MHz. In an embodiment, the increment of imaging frequency is more or less than about 0.5 MHz intervals. In an embodiment, the increment of imaging frequency is about 0.1 MHz. It should be appreciated, however, that the disclosed frequency range and adjustment increment may change as improvements in ultrasound imaging equipment become available, and/or to implement various embodiments of the present invention on non-ultrasound based medical imaging technology. Thus, the ranges noted above are not intended to be limiting.

[0020] According to another embodiment of the present invention as shown in Figure 2, the medical imaging system may further be provided with signal attenuation compensation capabilities. Signal attenuation generally refers to a reduction in signal quality, which may be caused by ultrasound pulses passing through different body tissues, structures, and fluids, such as for example calcification layers that absorb or scatter ultrasound energy. The resulting reduction in reflected ultrasound energy may result in degradation of the received echo signal quality.

Such reduction in reflected ultrasound echo energy, and thus image signal quality may be compensated for by increasing or decreasing the imaging frequency from the frequency that typically provides an optimized image of a given imaging depth. Thus, the imaging frequency determined in step 120 may be further adjusted upon or after being implemented in step 130 to compensate for signal attenuation.

[0021] As shown in Figure 2, an ultrasound image is received from the catheter-based ultrasound probe in step 210. The medical imaging system then, in step 220, determines a signal attenuation in the received ultrasound image. In step 220, the system may compare the measured received echo energy to the energy that would be expected if the attenuation matched expected values for the imaging depth. If the received energy is less than the expected energy, attenuation over the path length may be greater than the prediction or assumption. Similarly, if the received energy exceeds the expected energy, the actual attenuation may be less than the prediction or assumption. Attenuation may also be calculated using other methods, including an electronic table look up using the received or measured path length as an input, or an algorithm, such as a linear gradient, using the received or measured path length as an independent variable.

[0022] Once the signal attenuation has been determined in step 220, the medical imaging system then automatically determines an imaging frequency that corresponds to a reduced signal attenuation in step 230. By way of example, if the measured signal attenuation indicates less signal strength than expected (i.e., attenuation is greater than expected), such as due to the ultrasound pulse passing through a calcification layer, the determined imaging frequency may be an imaging frequency one (or more) increments (e.g., about 0.5 MHz or

about 0.1 MHz, according to various embodiments) below (i.e., a lower frequency) that determined in step 120. If measured signal attenuation is less than expected, the imaging frequency may be increased in order to provide finer resolution of features at the selected imaging depth.

[0023] The medical imaging system then adjusts the imaging frequency of the system in step 240 to the determined imaging frequency that corresponds to the measured signal attenuation. According to an embodiment of the present invention, the medical imaging system may then verify that the change has improved the signal attenuation condition by re-running steps 220, 230, 240. In this manner, the medical imaging system may automatically re-adjust for signal attenuation with minimal user interaction required. According to an embodiment, the imaging system may also automatically adjust time-gain compensation in response to measured signal attenuation, such as by adjusting the slope of a linear algorithm (e.g., increasing or decreasing gain G where time-gain compensation for a given point in the image = G * t + C, where t corresponds to the time corresponding to the point of interest and C is a constant).

[0024] According to another embodiment of the present invention as shown in Figure 3, the medical imaging system may be provided with a frequency scanning capability. More specifically, in step 310 the medical imaging system receives a user request for a scan through a range of frequencies to identify features at various distances, features including any number of viewable structures such as tissue masses, anomalies, etc. In step 320 the medical imaging system determines a "next" imaging frequency from the range of available frequencies. By way of example, if the scan is operating at its first cycle, the "next" imaging frequency may be the first available imaging frequency (e.g.,

2.0 MHz for the medical imaging system previously discussed or the current imaging frequency +/- the delta frequency). The medical imaging system then adjusts the imaging frequency in step 330 to the frequency determined in step 320. After an ultrasound image from the catheter-based ultrasound probe is received in step 340, the medical imaging system then determines whether the frequency determined in step 320 is the last imaging frequency in the range of available frequencies. If not, the medical imaging system re-runs step 320, else the process ends in step 360. Alternatively, steps 310 through 350 may be performed until stopped by the operator.

[0025] According to another embodiment of the present invention, the medical imaging system may be provided with an optimization feature as shown in Figure 4. In particular, in step 410 the medical imaging system receives a user request for an optimized image of a feature of interest, indicated by the point of focus set by the user, or assumed by default to be at 75% of the imaging depth. As an example, once the scanning process shown in Figure 3 has completed, a user may desire an optimized image of one of the features discovered during the scan and presented on the ultrasound image display. Alternatively, an "auto-recognize" feature may be provided that automatically recognizes features and initiates the request received in step 410.

[0026] Referring to Figure 4, the medical imaging system in step 420 determines an imaging frequency that corresponds to the optimized image based on the measured depth to the feature. The determination of an imaging frequency may assume physical properties for intervening tissues, including in an embodiment, assuming properties based upon detected intervening structures and fluids and measured parameters (e.g., continuity of imaged tissue, received echo signal strength, etc.).

Alternatively, using the scan of Figure 3 as an example of a starting point, if a feature becomes apparent at about 4.0 MHz during the frequency scan, the medical imaging system may select 4.0 MHz in step 420.

[0027] In step 430 the medical imaging system then adjusts the imaging frequency to the frequency determined in step 420. This may be followed by a confirmation step that queries the user whether the image has been sufficiently optimized. If the user responds that further optimization is required, then the process shown in Figure 4 may repeat (even with a smaller delta frequency).

[0028] In an another embodiment illustrated in Figure 4, the medical imaging system may include an image recognition and processing capability that assists in the optimization process. Specifically, following step 430, the image processing capability determines a measure of the image quality of the feature selected for imaging, such as by calculating a measure of resolution by measuring the definition of a boundary. For example, the image processing capability may determine the range over which echoes from a surface are received along a vector, which may be combined with statistical measures of the changes in intensity along the vector in the vicinity of the structure.

[0029] After an image quality (e.g., resolution) measure has been obtained for an initial frequency (F_0), the medical imaging system adjusts the imaging frequency of the catheter-based ultrasound probe in step 450 to a higher or lower frequency (F_1) and obtains another image. In step 450, the frequency may be adjusted up or down as determined by the imaging processing system as necessary to determine if optimum image quality (e.g., resolution) is achieved. By way of

example, the subsequent discussion assumes step 450 increases frequency the first time through the process (default), but the process may be implemented by decreasing the frequency the first time through. In applications where moving tissues, such as muscles and structures of the heart, are imaged, the second image may need to be taken (timed or triggered) so as to correspond to a similar configuration as in the first image so that image quality measurements can be compared. In a particular embodiment suitable for use in intracardiac imaging, the first and second images are timed or initiated based upon an input (e.g., an ECG signal) to occur at the same point in the cardiac cycle. By acquiring the second image at or nearly at the same point in the cardiac cycle as the first image, measures of image quality in the two images may be compared because the same structure will appear at approximately the same position (e.g., imaging depth) in both images.

[0030] In step 460, the image obtained at the new frequency F_1 is processed to determine a measure of the image quality (e.g., resolution) of the feature selected for imaging. Then, in step 470, the two measures of resolution for images taken at F_0 and F_1 are compared to determine if the image quality (e.g., resolution) is improved or degraded as a result of the change in imaging frequency.

[0031] In step 480, the medical imaging system determines whether to further adjust the frequency or whether an optimum frequency was obtained. If there is an improvement in image quality (e.g., resolution) when the imaging frequency is increased from F_0 to F_1, then the process returns to step 450, sequentially increasing (or decreasing) the frequency to new frequency F_i and comparing the resulting image quality (e.g., resolution) measurements. Steps 450 through 480 are repeated until the system determines there is no change or a

degradation in image quality (e.g., resolution) when frequency is increased from F_{i-1} to F_i. When that determination is made, the medical imaging system sets the imaging frequency to the frequency that provided the best measure of image quality (e.g., F_{i-1}) in step 490.

[0032] If the first comparison of the measures of image quality (e.g., resolution) in steps 470 determines that the resolution is unchanged or degraded by increasing the frequency from F_0 to F_1, then in step 480 the medical imaging system determines that the optimum frequency may be lower than the initial frequency (F_0). In that case, the process returns to step 450 where the imaging frequency is decreased to F_1. Then steps 460 through 480 are performed to determine if lowering the imaging frequency improved the image quality (e.g., resolution) of the desired feature. Steps 450 through 480 are repeated until the system determines there is no change or a degradation in image quality when frequency is decreased from F_{i-1} to F_i. When that determination is made, the medical imaging system sets the imaging frequency to the frequency that provided the best measure of image quality (e.g., F_{i-1}) in step 490.

[0033] As set forth in the aforementioned embodiments, medical imaging systems have been disclosed with autofrequency selection that provide a user with relatively simple and efficient operations of a given medical imaging system. Additional features such as frequency scanning, signal attenuation compensation, and image optimization may be utilized as desired. Further, a medical imaging system according to the present invention may merge or correlate ultrasound images with other medical information, including concurrent instrumentation data, such as electrocardiogram (ECG) data. For example, in medical procedures in which the imaging system is used to image portions of a

patient's heart, intracardiac electrophysiology catheters may also be present in the heart. In such procedures, displaying ECG data (such as a trace moving across the screen) on the same monitor that displays ultrasound images would aid the physician. Such ECG data may be correlated to the ultrasound images so the current ECG trace(s) is displayed along with the current ultrasound image. The ECG data may be further correlated to the image so the display shows only the ECG trace of the ECG catheter that is presently imaged by imaging system.

[0034] The foregoing description of various embodiments of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The embodiments were chosen and described in order to explain the principles of the invention and its practical application to enable one skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated.